Reply to comment by A. Revil on ”Seismo-electrics, electro-seismics, and seismo-magnetics for earth sciences” by L.Jouniaux and F. Zyserman

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Reply to comment by A. Revil on Seismo-electrics, electro-seismics, and seismo-magnetics for earth sciences by L.Jouniaux and F. Zyserman

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Abstract.
We detail below our answers to the comment, although we think there is a major conflict of interest guiding this comment, as already shown before (see Allègre et al. (2011); Jouniaux et al. (2010) and Johnston et al. (2002); Glover (2007); Nicollin et al. (2007); Kuwano et al. (2007)).

1 Introduction

We answer below point by point.

2 Answers

1. We agree that the limitation of the seismoelectric method is the smallness of the conversions: it is exactly what we wrote in the abstract and in the introduction.

2. We replaced induced signals by: the interfacial conversion.

3. We added: electromagnetic, and gravimetric methods.

4. We added: including seismoelectrics and electroseismics, just after: The seismo-electromagnetic method; because the electroseismics can investigate deeper than seismoelectrics (see Thompson et al. (2005). We modified several thousand metres depth by: the order of one thousand metres depth.

5. Unfortunately the mobility can not be quantified in relative velocity of the fluid compared to the rock matrix. A high fluid mobility is expected to be encountered when the permeability is not too low and when the clay-content is not too high.

6. We wrote that the interface conversion is generated when a seismic wave encounters a boundary in physical properties between two media. So, of course, the media can be inhomogeneous.
The effect of water-content on the seismoelectric conversions has been studied by extending the Pride's theory, taking into account the water-content, by Bordes et al. (2015); Warden et al. (2013); Zyserman et al. (2012); Strahser et al. (2011), according to studies on the effect of water-content on the electrokinetic coupling by Perrier and Morat (2000); Jouniaux et al. (2006); Jackson (2010); Allègre et al. (2010, 2011, 2012, 2015).

7. Actually we did not read this book yet. According to the time needed to write this review, and the editorial process, we wrote this part before the publication of this recent book.

8. We wrote exactly that electro-osmosis was first observed by Reuss (1809) and Wiedemann (1852).

9. Pride and Haartsen (1996) extended Pride's theory by including the effects of anisotropy: From the abstract of this reference, we transcribe literally: "...The governing equations controlling the coupled electromagnetic-seismic or "electroseismic" wave propagation are presented for a general anisotropic and heterogeneous porous material." In Section I.A the fully coupled equations (involving seismic-to-electromagnetic and electromagnetic-to-seismic

conversions) for the mentioned type of porous materials are presented, and thoroughly studied in following sections. Thus, we do not agree with the assertion that Haartsen and Pride did not propose an anisotropic seismoelectric theory.

10. The equation 21 is the volumetric charge density expressed as a function of permeability:

$$Q_V = -\frac{C_{s0}\sigma_0}{K}, \tag{1}$$

with K the hydraulic conductivity (in m/s).

In this expression, the volumetric charge density Q_V corresponds to the net amount of charge per unit pore volume of the medium (in C m^{-3}) (p.683 in Revil and Linde (2006)):

$$Q_V = -\frac{S}{V_{pores}} Q_{s0}; \tag{2}$$

Q_{s0} includes the contribution of the charge density due to the active sites covering its surface Q_0 and the charge density of the Stern layer Q_β. Q_V is defined by eq. 23 in Revil and Linde (2006) and cations are assumed to follow a Boltzmann distribution, as in Pride (1994).

Eq.1 implies that if the volumetric charge density is deduced from measurements of the streaming potential coefficient C_{s0} and the rock electrical conductivity σ_0 is also measured, there exists an inversely proportional dependence between Q_V and permeability, if the variations of $C_{s0}\sigma_0$ are not important compared to the variations of the permeability. We have no knowledge of any carried out experiment where Eq.1 has been validated through independent measurements of permeability and charge density.

Therefore, using this equation to calculate Q_V does not prove the existence of a real link between it and the permeability, because this link is assumed by the expression itself!. Unfortunately the volumetric charge density has been calculated using this equation in many papers.

In Jardani et al. (2007) it is written that the measurement of C can be used to determine the values of Q_V. In their Figure 1 Jardani et al. (2007) have reported the value of Q_V for different measurements of C. They observe that for a variety of rocks and ionic strengths of the pore water, Q_V depends mainly on the permeability of the rock.

Since we know that C is inversely proportional to the fluid conductivity, and that σ is also proportional to the fluid conductivity, it implies that

$$Q_V = -\frac{\epsilon\zeta}{\eta F K} \tag{3}$$

(assuming no surface conduction) with F the formation factor. So it is not surprising that this Q_V, calculated from eq.1 does not depend on the fluid conductivity and is inversely proportionnal to the permeability, since the formation factor variation is not so large as the permeability variation (ten orders of magnitude).

In Boleve et al. (2007) the table 3 gives values of Q_v (C/m^3) calculated again from the relation between the electrokinetic coefficient, the rock conductivity and the permeability, showing therefore a decrease of Q_v with increasing permeability. In Revil et al. (2007) Q_V is also calculated using this equation (eq. 111 in their paper).

Finally the author himself in Revil et al. (2005) deduced Q_V values from CEC measurements: two Q_V values are deduced: Q_V = CEC $\rho_g(1-\phi)/\phi$ (total charge density C/m3), and estimated $Q'_V = (1-fQ)Q_V$, with fQ = 0.98 (pore charge density). The second value of Q'_V is usually used in the relation between Q_v and K described above. So finally this value Q'_V is only 2% of the Q_v value deduced directly from CEC. These values are between 0.5 and 3 10^6 C/m3 (for 4 samples). Unfortunately there is no permeability measurements on these samples, so that the relation between Q_V and the permeability is not demonstrated.

Therefore the eq.1 has not been validated using independent measurements of permeability and charge density. This equation has been used to calculate Q_V, using permeability values, to deduce that Q_V is inversely related to the permeability. Therefore this approach is considered not appropriate and should not be used. We advice the reader to use the electric current density as a function of the pressure, rather than as a function of the velocity and Q_V.

11. We describe the Helmholtz-Smoluchowski eq. (eq.22) by citing Dukhin and Derjaguin (1974), which is a study much earlier than the paper of 2003 suggested by the author.

12. It is always more precise to deduce the surface conductivity from many measurements of rock conductivity at various salinities, especially in the low salinity domain.

13. The formation factor is deduced from several measurements of rock conductivity as a function of the fluid conductivity, in the high-salinity domain (Archie, 1942; Gueguen and Palciauskas, 1994; Man and Jing, 2000; Snyder, 2001; Jouniaux et al., 2006).

14. The effect of temperature has been modelled by Morgan et al. (1989), ten years before the study cited in the Comment. We did not cite the study mentioned by the author because in it the problem is oversimplified by not taking into account the effect of temperature on the fluid viscosity although it is the most dominant term in the temperature-dependence of the streaming potential coefficient.

15. Notice that we asserted that the inversion method should be validated with borehole sismoelectric signals observed in the field or in laboratory, so we think we are being cautious here.

16. We invite the readers to make their opinion themselves, by reading our paper.

17. We agree, the verb has been replaced by summarized.

18. As written in the caption, this figure comes from Thompson et al. (2007) (figure 7 p. 432 of their paper).

19. Fig. 3 has been drawn by L. Jouniaux herself, for the paper Jouniaux and Ishido (2012), which is referenced in the caption of the figure.

20. We wrote it is a seismoelectric coupling.

21.This figure has been elaborated by L. Jouniaux herself for the paper Jouniaux and Bordes (2012), which is cited in the caption of the figure.

22. We described this figure to show that the amplitude is decreasing with the conductivity. The solid curve is the unmodified model of EK-Biot for the glass samples; the dashed line is the model modified including a surface conductance for the sand samples, showing that the Pride's theory allows to predict the electrokinetic behaviour as a function of the conductivity. This point is added in the caption.

23. This figure has been published in Jouniaux (2011).

3 CONCLUSIONS AND PERSPECTIVES

We ask the editorial committee of Solid Earth to remove the accusations of unethical behaviour, and the "heavily borrowed" accusation, which are defamation.

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